Design and Results of a 1.3 MW CW Klystron for LEP

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Abstract

The development of a high power CW klystron prototype delivering 1.3 MW at 352 MHz is presented. The design was carried out using CAE / CAD tools. Particular attention was given to design optimizations with regard to the modulating anode electron gun, the focusing system and the RF region for a wide range of operating conditions typical for accelerator applications. Two new technological features were introduced, PHILIPS low temperature cathode for long life stable operation and a multipactor suppression coating on the RF output window. Test and operational results is included in the presentation.

I. INTRODUCTION

For the increase of the LEP energy from 55 GeV to 100 GeV additional RF units with superconducting cavities and 1.3 MW cw klystrons will be installed in the LEP machine by 1994. The design of the new klystron must be made such that it can replace the presently installed 1 MW cw klystron. This restricted the development mainly in the overall length. Testing one of our 1 MW klystrons YK 1350 in 1.3 MW operation we found a small decrease in efficiency and stability but all components withstand the 30% increase in power without failure. Main objective of the 1.3 MW klystron development was therfore the improvement of stability and efficiency.

II. GUN DESIGN

The new 1.3 MW klystron is designed to operate at three different operation points as:

I. 1.3 MW 100 kV 20 A $\eta \geq 65\%$
II. 1.0 MW 88 kV 18 A $\eta \geq 63\%$
III. 0.7 MW 77 kV 15 A $\eta \geq 60\%$

The difficulty in the design of a high power klystron gun with a modulating anode is to find a compromise between full power and medium/cutoff operation. The first CAE design with EGUN [1] was a confined flow beam without ripple at full beam power (100 kV / 20 A, see Figure 1A). But when calculating the beam shape at lower levels of modulating anode voltage as shown in Figure 1B the beam ripple increased more and more until it hits the drift tube at a beam current of 2 A. Changing the shape and magnitute of the focusing magnetfield we could get a final design shown in Figure 1C/D which fulfills cutoff operation

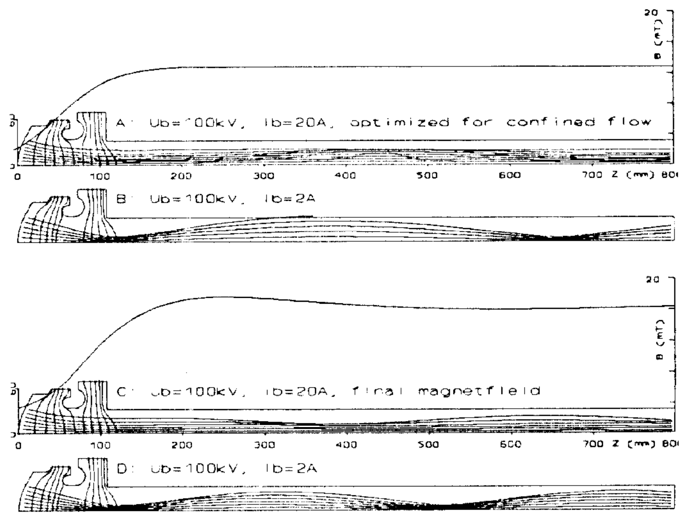

Figure 1. Static gun design

as well as full power operation with an acceptable beam ripple. A next step was to replace the "B" - type cathode by the PHILIPS low temperature cathode which accomplishes the strong demands of long life stable emission, low evaporation rate, high current density and low working temperature in modern electronic tubes. The PHILIPS low temperature cathode [2] is a "M"-type cathode and consists of a porous tungsten pellet matrix which is impregnated with BaO, CaO and Al_2O_3 in a molar ratio of 5:3:2. The

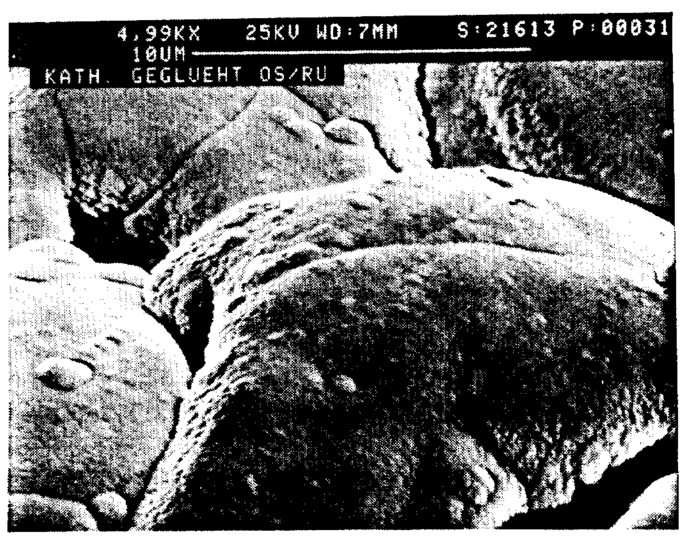

Figure 2. SEM picture of OsRu coated "M"-type cathode

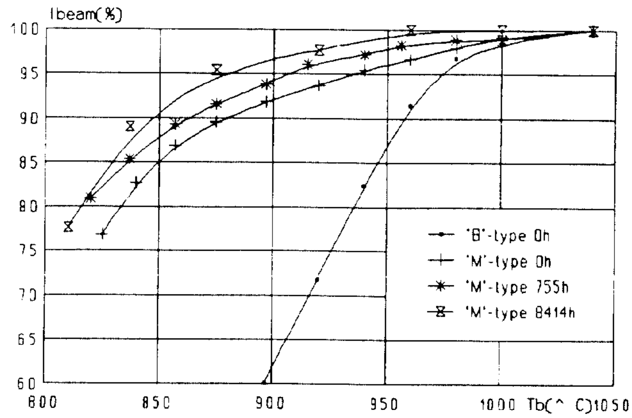

Figure 3. Underheating and liftime plot of cathodes

emission surface is coated with a film of osmium-ruthenium with a thickness of 0.5μm-1μm. The work function is 0.2eV lower than that of the uncoated cathode. Therefore "M"-type cathodes can be operated at a temperature about 80°C - 100°C lower than an uncoated cathode. A comparison of underheating behavior between "M"-type and "B"-type cathodes is shown in Figure 3 together with a life time report.

III. RF - DESIGN

Computer simulations with the particle in cell code FCI [3] starting from the 1 MW cw YK 1350 RF design with 6 cavities (5 fundamental, 1 harmonic) showed that an increase in efficiency could only be obtained by increasing the spacing of adjacent cavities. In order to keep the overall length of the klystron unaffected we droped one of the two penultimate buncher cavities. During the optimization process we varied spacing and frequency of each cavity as well as loaded Q of output cavity taking into account efficiency, gain and stability at the desired dc operational points. At the end of the optimization phase we could obtain the calculated values listed in Table 1.

Table 1
Calculated results of 1.3 MW klystron YK 1353

Ub/kV	Ib/A	Po/kW	η/%	G/dB
100	20.0	1394	69.7	39.4
88	17.5	1070	69.5	39.9
77	13.8	662	62.3	38.6
77	21.5	1010	61.o	41.6

Klystrons with high efficiency tend to instabilities when operating into a mismatched load. Depending on phase angle one can observe an increase in modulating anode current and sidebandoscillations near RF carrier on output signal. These instabilities have their origin in electrons, which are reflected and accelerated in reverse direction by the high output gap voltage. Reaching the gain cavity they build an internal loop which may cause oscillations. Figure

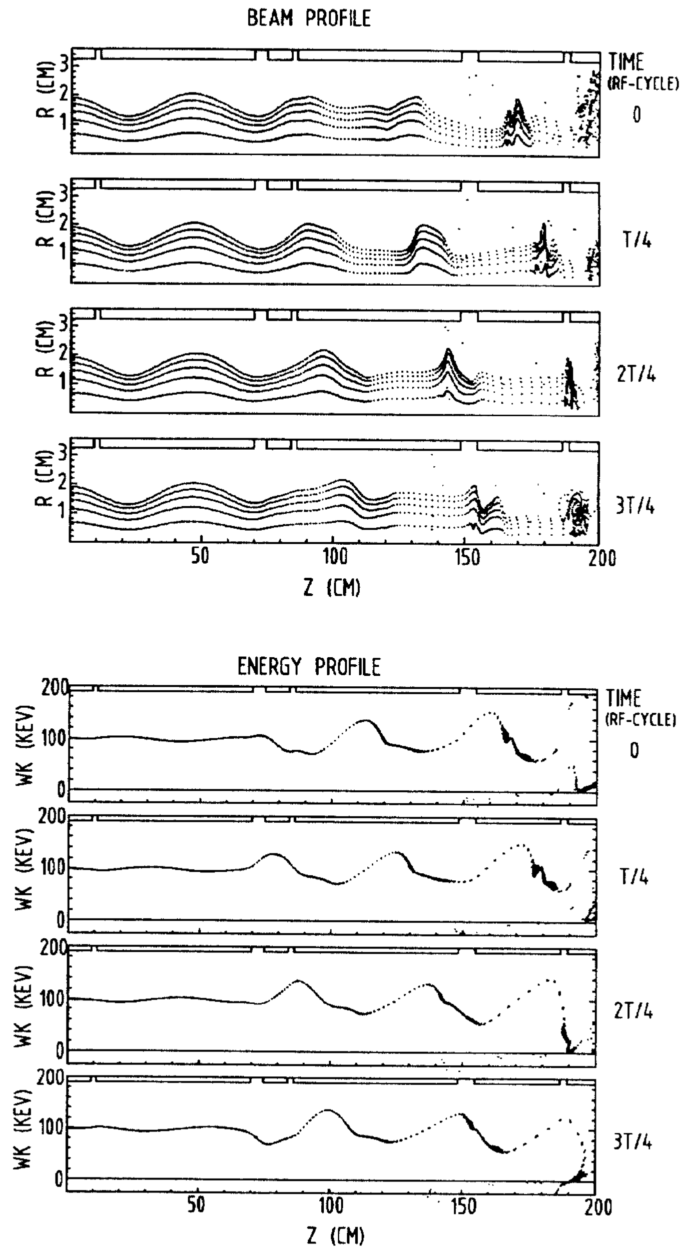

Figure 4. Beam and energy profile of YK1353 under mismatch condition.

4 shows a FCI simulation of a load mismatch operation (VSWR=1.5) at a phase angle which cause high gap voltage. Besides the BEAM PROFILE where the location

of the electrons is calculated in dependence of time, the ENERGY PROFILE is a good indicator for backstreaming electrons shown here with negative energies. Further simulations demonstrated that detuning the penultimate cavity by a few percent to higher frequencies reduced instable operation and did not affect efficiency.

IV. OUTPUT WINDOW

The output window is a forced air coold Al_2O_3 ceramic koaxial window as it was used in the 1 MW tube. To suppress multipactoring it is additionally coated with a thin film of TiN. This is done by plasma supported CVD. During RF processing and testing the coated prototype window no multipactor accured even in low and medium RF power range, while the older uncoated windows very often showed multipactoring.

V. TEST RESULTS

The klystron was tested under different operational conditions as shown in Table 2. A comparison to the calculated results in Table 1 demonstrates excellent agreements.

Table2
Test results of YK 1353

PHILIPS YK 1353
1.3 MW cw Klystron 352 MHz

Operating data

- 1.3 MW at 100 kV / 19.3 A η = 67.5 %
- 1.0 MW at 88 kV / 17.1 A η = 66.5 %
- 1.0 MW at 77 kV / 22.4 A η = 62.0 %
- 0.7 MW at 77 kV / 15.2 A η = 60.3 %

Typical data at 1.3 MW operation:

Beam voltage	:	100.0	kV
Beam current	:	19.3	A
Anode Voltage	:	53.0	kV
Drive power	:	70.0	W
Gain	:	41.0	dB
Collector dissipation	:	1.0	MW
Body dissipation	:	16.0	kW

Remarkable is the operation point 1MW at 77kV/22.4A with an efficiency greater than 60% and a beam perveance of 1.05 μP. An overload test at 1.35 MW for 1 hour showed no electrical or thermal instabilities. A load mismatch test was also made with a movable teflon plate of VSWR = 1.2 inserted in the wavequide between klystron and matched water load. At 1 MW operation or below no intabilities like sidebandoscillations occured. At 1.3 MW output power sidebands appeared 45 dB or less below carrier at transformed reflection phase angles around 0 degrees.

REFERENCES

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[3] "High-Power Klystron Simulations using FCI-Field Charge Interaction Code." T. Shintake, KEK Report 90-3 (May 1990)